THE MARS ORGANIC ANALYZER: INSTRUMENTATION AND METHODS FOR DETECTING TRACE ORGANIC MOLECULES IN OUR SOLAR SYSTEM. Amanda Stockton[1], Jungkyu Kim[2], Peter Willis[1], Robert Lillis[3], Ronald Amundson[4], Luther Beegle[1], Anna Butterworth[3], David Curtis[3], Pascale Ehrenfreund[5], Frank Grunthaner[4], Robert Hazen[6], Ralf Kaiser[7], Michael Ludlam[3], Maria Mora[1], James Scherer[4], Paul Turin[3], Kees Welten[3], and Kenneth Williford[1], and Richard A. Mathies[4*] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, [2]Texas Tech University, Lubbock, TX, [3]University of California Berkeley Space Science Laboratory, Berkeley, CA, [4]University of California, Berkeley, CA [5]George Washington University, D.C. [6]Carnegie Institution of Washington, George Mason University, VA, [7]University of Hawaii, Honolulu, HI. *Corresponding author: Richard A. Mathies, College of Chemistry, University of California, Berkeley, CA.

Introduction: The Mars 2020 Mission leverages Mars Science Laboratory Curiosity rover heritage to perform an investigation on Mars with objectives including: (A) Determine environmental habitability, search for regions and materials with high biosignature preservation potential, and search for evidence of past life, and (B) Scientifically select and cache well characterized samples for possible return. The Mars Organic Analyzer (MOA), developed and proposed for Mars 2020 in January 2014, was designed to meet these objectives by providing the mission with capability to analyze a broad range of organic molecules with sub-part-per-billion limits of detection. This analytical sensitivity is needed to characterize the habitability of environments, to characterize biosignature preservation potential, to search for evidence of past life, to characterize samples for return to Earth, and to measure and characterize any possible forward contamination.

MOA Science: The MOA will address Mars 2020 objectives by determining the identity and concentration of a wide range of organic molecules including amines, amino acids, aldehydes, ketones, organic acids, thiols and polycyclic aromatic hydrocarbons (PAHs) in Martian samples with sub-part-per-billion sensitivity.

MOA Instrument: The MOA instrument is based on extensive instrument and method development and field testing [1]. Sub-part-per-billion sensitivity is achieved with an integrated instrument that first efficiently extracts organic molecules from Martian soils and drill fines using subcritical aqueous extraction (SCAE) [2]. The molecular extracts are passed to a multilayer integrated microdevice (Figure 1) that consists of a Programmable Microfluidic Analyzer or PMA and a microfabricated capillary electrophoresis (μCE) device. In the PMA [3], the organic compounds are autonomously labeled according to their chemical functional groups with fluorescent reagents specific for amines, aldehydes, ketones, organic acids and thiols. The labeled molecules (or naturally fluorescent PAHs) are then passed to the μCE system for high-resolution electrophoretic separation followed by high sensitivity laser-induced fluorescence detection on one of the four

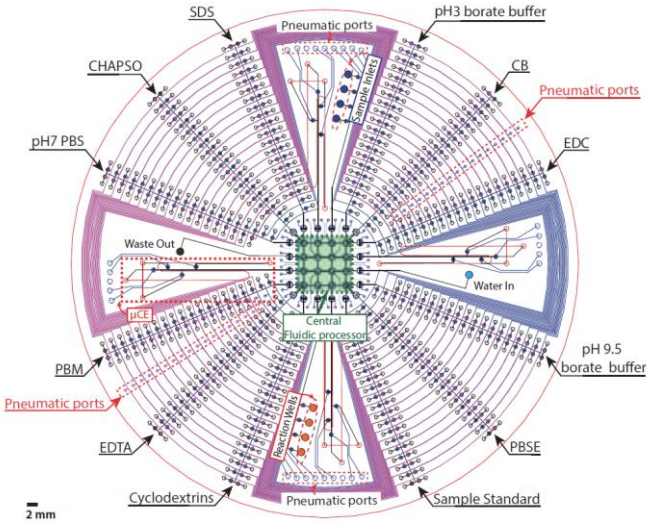

Figure 1: *MOA Programmable Microfluidic Analyzer layout. This 100-mm diameter multilayer glass-PDMS device with 516 multiplexed valves contains the dried reagents needed to perform all MOA chemical analyses upon 38 separate sample extracts on Mars.*

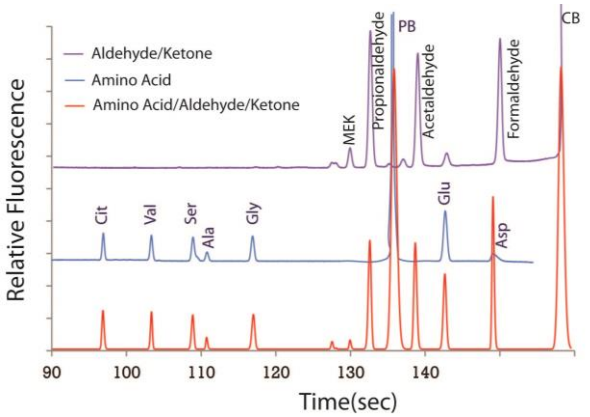

Figure 2*: Exemplary MOA analysis of a mixture of various amino acids, aldehydes and ketones. High sensitivity labeling, CE separation and detection enables sub-part-per-billion sensitivity.*

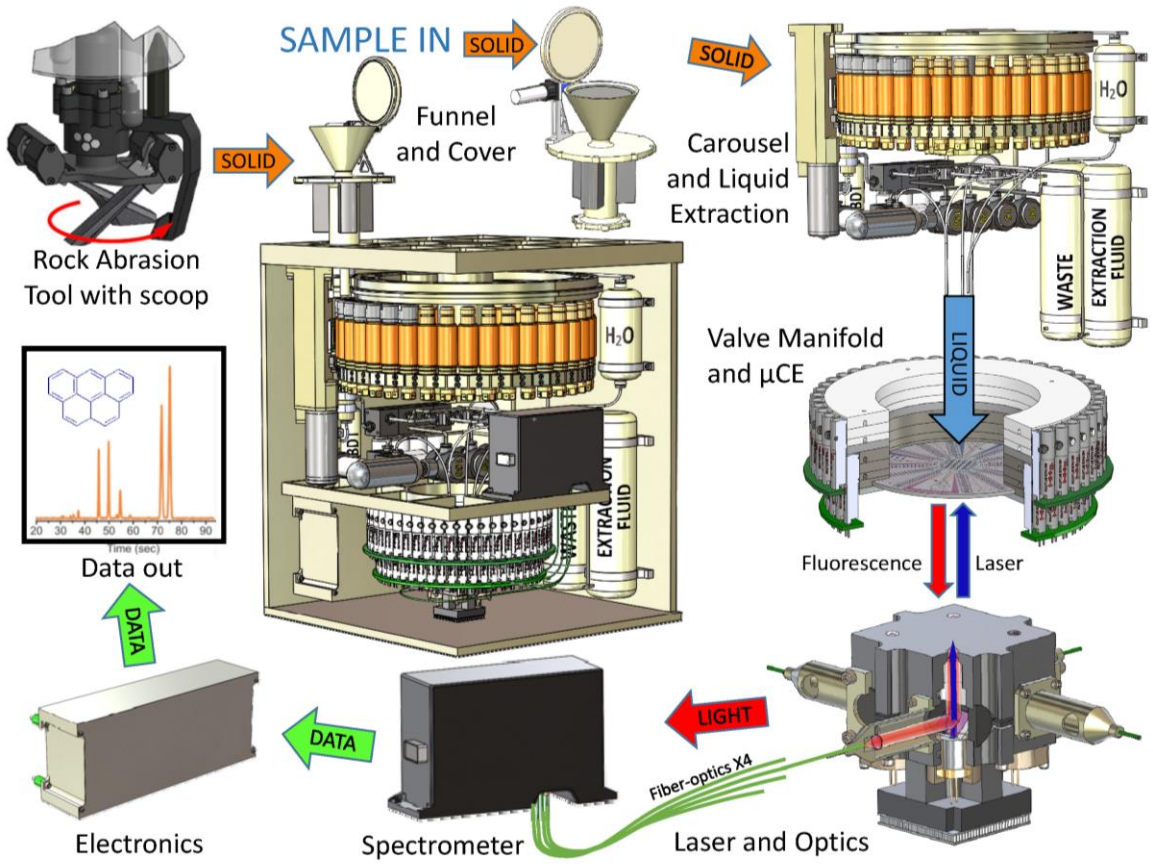

***Figure 3**: In the MOA investigation, drill fines are passed through a funnel to the extraction cup and aqueous solvent at elevated T, P is forced through the drill fines, extracting organic molecules. This extract is then transported to a programmable microfluidic sample processing system or PMA for fluorescence labeling followed by injection, separation and high sensitivity detection on a microfabricated capillary electrophoresis channel to reveal the identity and concentration of a wide variety of organic molecules.*

independent CE channels [4]. The dye-labeled organics are identified by their electrophoretic mobility (Figure 2) and the PAHs are identified by their mobility and their fluorescence spectrum detected on one quadrant of a CCD spectrograph. The coupling of efficient non-perturbative SCAE, high sensitivity labeling and detection results in sub-part-per-billion detection limits that dramatically enhance our ability to perform in situ detection and characterization of organic molecules on Mars and other solar system bodies including moons and comets.

MOA Heritage: The MOA is based on over 15 years of development work at UC Berkeley and JPL [1-4]. MOA portable prototypes have been field tested in the Panoche Valley, CA and in the Atacama Desert in Chile, where amino biomarkers of ancient life were detected and dated based on their chiral ratios [1].

MOA Technical Presentation: The laboratory development of the extraction, labeling, processing, separation and detection methods that make the MOA instrument possible will be presented. The engineering design that integrates all of these functions for the analysis of up to 38 samples on the surface of Mars including the fiber optic coupling of the four detection systems to a single spectrograph and CCD will be presented. Overall MOA is a compact 12 kg, 5 watt, 22 x 22 x 29 cm instrument (Figure 3) that only requires 25 MB of data return for the analysis of 38 samples. While targeted for Mars, MOA could be repackaged for other planetary science missions requiring highly sensitive in situ organic analysis.

References: [1] Skelley A.M., Scherer J.R., Aubrey A.D., Grover W.H., Ivester R.H.C., Ehrenfreund P., Grunthaner F.G., Bada J.L., Mathies R.A. (2005) *PNAS USA, 102*, 1041-1046. [2] Beegle L.W., Kirby J.P., Fisher A., Hodyss R., Saltzman A., Soto J., Lasnik J., Roark S. (2011) *Aerospace Conference*. [3] Kim J., Jensen E., Stockton A., Mathies R.A. (2013) *Anal. Chem., 85*, 7682−7688. [4] Mora M.F., Stockton A.M., Willis P.A. (2012) *Electrophoresis, 33*, 2624–2638.